R842-09

ERIC REPORT RESUME

ED 010 207 1-31-67 24 (REV)
RECENT DEVELOPMENTS IN DATA COLLECTION AND ANALYSIS FOR EXPERIMENTS.
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TGZ65143 UNIVERSITY OF PITTSBURGH, LEARNING R AND D CTR., PA.
BR-5-0253-9
-FEB-66
EDRS PRICE MF-$0.09 HC-$0.56 14P.

*COMPUTERS, *COMPUTER PROGRAMS, *DATA COLLECTION, *DATA ANALYSIS, EXPERIMENTAL PROGRAMS, PITTSBURGH, PENNSYLVANIA

THIS WORKING PAPER OFFERS A BRIEF DESCRIPTION OF THE UTILIZATION OF COMPUTERS AS CONTROL DEVICES, LISTING BOTH THEIR ADVANTAGES AND DISADVANTAGES. SUCH OTHER APPLICATIONS AS SIMULATION AND 'DATA PROCESSING' WERE NOT COVERED IN THIS DOCUMENT. (LP)

RECENT DEVELOPMENTS IN DATA COLLECTION AND ANALYSIS FOR EXPERIMENTS

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February, 1966

The research and development reported herein was performed pursuant to a contract with the United States Office of Education, Department of Health, Education, and Welfare under the provisions of the Cooperative Research Program.

Recent Developments in Data Collection and

Analysis for Experiments

Whenever a symposium is organized, a set of titles is selected in such a way that the unifying theme of the several presentations is readily apparent. Then each participant faces the task of skillfully using his title as an introduction to the topic he is willing to talk about, with the added restriction that he try to avoid overlap with the other papers, which he has not seen.

The original title of this paper was "Recent developments in data processing" and the combination of this title and the present title probably gives a much clearer i[illegible] of the topic I have in mind than either of them does by itself. More specifically, I plan to discuss the role of the computer in experiments as a device to control conditions, collect data and make analysis relevant to the ongoing control process.

Before getting into this more recent computer application, let me briefly mention applications which I will not discuss. Most of these can be broadly classified under the heading of "data processing." I will not talk about any statistical data processing in which a person presents data to the computer to be analyzed, summarized, collated, formatted, etc., or record keeping in which new data is added to some previously accumulated. The only recent development I shall mention in this area concerns a mythical (?) computer which bears the acronym GIGO. My colleague, Henry Hausdorff, who conceived of the machine, explains that the initials stand for "Garbage In, Garbage Out."

Another well known area of computer applications which will not be discussed is that of simulation. The simulation may be of another computer, as in digital simulation of analog computers, but we are generally more interested in the simulation of a person or group. This type of application can lead to insights into the processes involved in human behavior. Further, it is invaluable in determining the consequences of a particular mathematical model. Recent developments in this area, however, are more the accomplishments of individual researchers than of any developments in research methodology or the tools available.

The Computer as a Control Device

For several years the small or medium-sized computer has been used in industry to control some process by continuously adjusting various parameters. These process control systems are applied most frequently to continuous processes such as rolling mills, steel making, and batch blending. Typically, the variables involved are so fast-changing and so interrelated that it is impossible for an unaided operator to know exactly how to react to process disturbances. On the other hand, a computer system can perform an entire spectrum of functions ranging from simple data logging, in which it merely reports variables, to complete process control. Between these extremes lie various mixes of logging, supervision, and control.

In recent years, the behavioral sciences have evolved several parallel computer applications. That is the computer has been used to carry out experiments, collect the data, and ocassionally alter the experimental procedures on the basis of the collected data. The analogy of this application

to that of industrial process control should be even clearer when one considers the general area of computer-assisted instruction. In the latter case it is the learning process which is being monitored and parameters are varied on the basis of the students responses.

Present Computer-Controlled Experiments

Many of the experiments now being done in computer-assisted laboratories do not really take advantage of the computers capabilities. In fact, it is not an easy task to think of an experiment which can be controlled by a computer and cannot be duplicated with conventional experimental apparatus. The difficulty of this task may be due to rigidity in thinking brought on by traditional courses in research methodology. The primary advantage of the computer lies in its ability to modify the procedure on the basis of the collected data, but very few current experiments make use of this feature.

The ability of the computer to collect large amounts of data in short periods of time is one advantage currently being exploited, although mainly in nuclear physics experiments. It is also possible to put this ability to use in behavioral science applications. It is a simple matter for a computer to simultaneously collect data on latency of response, type of response, amplitude of response, physiological variables, etc., all with a high degree of accuracy and for more than one subject. This could be a disadvantage if the experimenter gathers data for a large number of variables just to see if anything comes out statistically significant. The saving grace for computers is that although such multiple data collection is technically possible, it is usually not economically desirable, if only because of the extra programming involved.

Computers have also been used quite extensively in the generation of stimulus materials. This is particularly appropriate when an oscilloscope is used for display. Given the dimensions on which stimuli can vary it is usually possible to write a program to generate all possible stimulus objects. In this manner the experimenter can have an extremely large pool of potential stimulus objects even though a large number of them may never be used.

A further advantage for the use of computers in conducting experiments is timing flexibility. It is possible for the experimenter to specify with a high degree of accuracy, the timing of all experimental events under his control. The flexibility of the computer allows the timing to be easily varied over trials, or to be conditional on the occurrence of other events.

Some Disadvantages of Computer Control

As long as I have listed some advantages of computer control, it is only fair that I also list some disadvantages. The most serious disadvantage is probably the limited number of response modes available. In many cases there is only one response mode, that of depressing a key on a keyboard. If facilities are available, one can adapt more sophisticated response devices for computer input, but for the typical experimenter the availability is limited. This situation is being alleviated as new response devices become more common. Devices recently developed, or under development, allow the computer to sense the movement of an electronic pencil, the location of a finger touch and the movement of blocks.

A further disadvantage of computer-assisted experimentation is the length of time it takes before an experiment can be implemented. I am re-

ferring to the time necessary for computer programming and debugging. Unless one plans to process a large number of subjects, or do a series of related experiments using the same general procedure, it may be more expeditious to carry out the experiment by conventional means. Once again, this is an area where steps are being taken to bring relief. In this case relief is in the form of special computer languages. Several languages for the presentation of instructional materials have reached different stages of development. A language for the acquisition of oceanographic data has also been created and hopes for a general experimental language do not seem out of place.

One disadvantage that holds for almost any computer program that is at all complex, is that one can never really be sure that a program will work for all possible cases until they have all been tried. This is probably more serious for experimentation than for analysis programs since there are usually several independently derived analysis programs to serve as checks on each other. Nevertheless, some analysis routines have been faulty and yet been used for long periods of time. It will be quite difficult to determine if the routines which obtain the data are in error.

<u>Equipment-Sharing vs. Time-Sharing</u>

In general, experiments run under computer control, particularly those using small computers, are done in an equipment-sharing manner. Different experiments are run at different times, with each being loaded into the computer as it is needed. In this mode of operation, each experimental procedure may use any or all of the available equipment.

An alternative to equipment-sharing is time-sharing, in which several experiments are conducted in a particular time period using a single computer. This is feasible since in a typical experiment the computer can spend over 90% of its time waiting for the subject to respond. The implementation of a time-sharing experimental laboratory requires a greater initial investment in programming but allows more efficient use of the major component of the laboratory, the computer. The computer which most readily adapts to this type of use is a small or medium sized computer in the $ 50,000 - $150,000 price range. A high input-output rate is desirable but a large amount of fast-access memory and great processing capability are not essential. A slower mass memory is important, however, for servicing even a small number of stations with any flexibility. This slower mass memory can be used for storing data, both current and background, decision and analysis programs, subject matter, and general service routines.

Implications for Data Analysis

There are implications that computerized data collection has for data analysis which are worth considering. I have already mentioned the relative ease with which large numbers of variables may be sampled. A feature worth considering in more detail is the possibility of altering the experimental procedure, or instructional sequence, on the basis of the analysis of previous responses.

Let me give some examples of situations which might benefit from this facility. I have been informed that a reasonable hypothesis in paired-associate learning is that the learning of a particular pair is facilitated

in proportion to the number of times it follows a correct response. This is a very difficult hypothesis to test unless you can vary the order of the list after each response. If the list order can be varied after each response, it is possible to randomly assign pairs to conditions of following a high percentage of correct responses and a low percentage of correct responses. Using a computer for list presentation and data collection makes the task quite simple.

There are many situations where a responsive display is desirable. This might involve plotting an equation, showing the output of an electrical circuit, etc. This can be viewed as a type of data analysis in that an analysis of the student's response uniquely determines the new stimulus. The new stimulus for the student, i.e., the waveform of the circuit's output, will be a function of the students response, i.e., the values he gave for resistors, capacitors, etc.

An example that is even more applicable for the area of educational research is the investigation of the effect of subject matter parameters on learning rate. In this type of study one varies the mode and manner of presentation, content variables, etc., in an attempt to optimize the learning rate for a subject. A problem in this area of research is that there are many effects which are not under the experimenters control, such as individual differences in students and time trends due to practice, fatigue, boredom and the like. If we could do away with some of these undesirable sources of variance, this could be viewed as a problem for response-surface methodology.

A tool that may be useful in computer presentation of subject matter, which has not been extensively investigated, is latency of response. In a drill situation one often uses N consecutive correct as a criterion for success. It seems reasonable that one could terminate the drill earlier if the latency of the correct responses were used as an additional indication of learning. An example may make this point more clearly. A spelling drill which we use for demonstration purposes in our computer-assisted laboratory, requires that a subject spell a word correctly more times than he spells it incorrectly before the word is dropped from the drill. In spelling a word like SCIENCE a subject may stumble on the I-E rule several times before getting the word right. Without getting into a debate on the merits of over-learning, I would like to suggest that instead of requiring the subject to spell SCIENCE correctly four or five times, we allow an alternative criterion of two correct responses with latencies well below his mean latency.

Real-Time Analysis

As experiments done under computer control, become more prevalent, more attention will have to be paid to developing appropriate statistical techniques for "real-time" analysis, i.e., analysis of the data while the experiment is in progress. Techniques which are described as "sequential statistics" are probably not adequate to the task. Listed under sequential statistics one finds measures of runs, auto-correlations and combinations thereof. It may be that auto-correlation will be particularly helpful in studying variables such as motivation or attention, which may behave in a cyclical manner. To this one might also add sequential designs such as fractional factorials, which are particularly helpful in exploratory studies,

but an abundant supply of techniques is missing.

Implementing real-time analysis techniques and using them for the modification of experimental procedures will lead to what might be considered by some to be another disadvantage of computer-assisted experimentation. The problem is that if an experimenter plans to make full use of the computer-assistance, he must consider all possible outcomes for stage one of his experiment if he plans to modify the procedure for stage two and must consider all possible outcomes of all possible variations of stage N if he plans to modify the procedure for stage N+1. This may be an overpowering restriction for some experimenters and they may choose to ignore some of the advantages of computer-assistance. For those of us who recommend this strange type of behavior, i.e., planning what to do with the data before collecting it, computer controlled experiments may offer a blessing in disguise.

In closing, let me say that although some people may see an advanced state of computer-assisted experimentation arriving very quickly, there are several inhibiting factors that I would like to mention. One involves an uncritical acceptance of computer accomplishment by those not familiar with computers. This is the "Did you see the computer that printed a picture of Santa and his reindeer?" type comment. This attitude of awe is often fostered by computer users who sometimes attribute slightly supernatural properties to their programs ("Then depending on the type of student, the computer gives him .. "). This combination tends to lessen the demands that computer users be particularly creative in their applications.

A final inhibitor is the tendency for the use of a computer to become a goal rather than a means to an end. It is very easy to get so carried away with programming that one does nothing else. One extreme example of this might be a person who spends so much time creating a program to write up studies that he never has time to collect any data to write up. Hopefully, these inhibitors will have negligible effects and computer-assisted laboratories will be rapidly implemented.